## What is claimed is:

- 1 1. A method for determining an attitude of an accelerating object
- 2 exclusively from acceleration and angular rate, comprising:
- determining an angular rate of the object for conversion into a direction
- 4 cosine matrix;
- determining a level frame acceleration value of the object based upon the
- 6 direction cosine matrix and an acceleration of the object;
- 7 generating a corrective rate signal based upon the level frame acceleration
- 8 value; and
- 9 updating the direction cosine matrix based upon the determined angular rate
- of the object and the corrective rate signal to obtain the attitude of the object.
- 1 2. The method of claim 1 further comprising:
- 2 extracting Euler Angles from the direction cosine matrix to represent the
- 3 attitude of the object.

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- 1 3. The method of claim 1 wherein the corrective signal includes a
- 2 correction component to correct for a heading deviation of the object.
  - 4. The method according to claim 1 further comprising:
- 2 performing temperature correction to angular rate and acceleration data to
- 3 temperature compensate the data which updates the cosine matrix, and to

- 4 temperature compensate the corrective rate signal to correct the updated cosine
- 5 matrix.
- 1 5. The method according to claim 1 further comprising:
- 2 performing frequency compensation of angular rate data to expand the
- 3 operational bandwidth of the angular rate data to provide updates to the directional
- 4 cosine matrix under dynamic conditions which the angular rate data alone would
- 5 not track, or which compress the bandwidth of the angular rate and acceleration
- 6 data to reduce noise and to reduce vibration sensitivity in the calculation of the
- 7 direction cosine matrix.
- 1 6. The method of claim 1 wherein the gain of the correction signal is
- 2 adjustable.
- 7. The method of claim 1 wherein calibrated data is obtained by
- 2 applying compensation parameters to the raw sensor data.
- 1 8. The method of claim 1 wherein an automated calibration procedure
- 2 provides the compensation parameters used to compensate the raw sensor data.
- 1 9. The method of claim 1 performed with gyros and accelerometers in
- which the calculation of direction cosine matrix is dependent on the angular rates
- measured by the gyros, and on the corrective rates determined from an

- accelerometer gravity reference algorithm, solved through integration, to normalize
  the direction cosine matrix.
  10. A self-contained system capable of determining an attitude of an
  - 10. A self-contained system capable of determining an attitude of an accelerating object exclusively from acceleration and angular rate, the system, comprising:

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- an acceleration sensor aligned with each of a plurality of orthogonallyoriented axes of rotation of the object for providing an acceleration value;
  - an angular rate sensor aligned with each of the plurality of orthogonallyoriented axes of rotation of the object for providing an angular rate value;
  - a processor for receiving the acceleration value from the acceleration sensor and the angular rate value from the angular rate sensor, and for executing a computer program that performs the steps of:
    - establishing a direction cosine matrix representation of attitude based upon the angular rate value;
      - determining a level frame acceleration value of the object based upon the direction cosine matrix and the acceleration of the object;
      - generating a corrective rate signal based upon the level frame acceleration; and
      - updating the direction cosine matrix representation based upon the angular rate of the object and the corrective rate signal to obtain the attitude

- of the object.
- 1 11. The system of claim 10 further comprising:
- a temperature sensor, coupled to the processor, for providing temperature
- data to compensate the angular rate sensors and acceleration sensors which provide
- 4 the update and correction to the update of the direction cosine matrix.
- 1 12. The system of claim 10 further comprising:
- a magnetic sensor, coupled to the processor, for providing heading data to
- 3 update the direction cosine matrix.
- 1 13. The system of claim 10 further comprising:
- a frequency compensation stage for frequency compensating the angular rate
- 3 sensors and acceleration sensors to provide enhanced dynamic response of, reduce
- 4 the noise in, and reduce the sensitivity to vibration of the updated direction cosine
- 5 matrix.
- 1 14. The method of claim 1 further comprising:
- 2 using a local level-plane predefined maneuvering Kalman Filter algorithm to
- 3 automatically estimate and provide gyro and accelerometer calibration coefficients.
- 1 15. A self-contained system for determining an attitude of an accelerating
- 2 object exclusively from acceleration and angular rate, the system comprising:

- a plurality of acceleration sensors configured to determine an acceleration
- 4 rate of the accelerating object, each acceleration sensor being aligned with one of
- 5 a plurality of orthogonally-oriented axes of rotation of the object;
- a plurality of angular rate sensors configured to determine the angular rate
- of the accelerating object, each angular rate sensor being aligned with one of the
- 8 plurality of orthogonally-oriented axes of rotation of the object;
- 9 wherein an initial calibration is performed for the plurality of acceleration
- sensors and angular rate sensors disposed about the orthogonally-oriented axes of
- 11 rotation for producing calibration data;
- a processor coupled to the acceleration sensors and the angular rate sensors
- 13 and including a memory for storing calibration data, the processor configured to
- 14 determine the attitude of the accelerating object by:
- converting the acceleration rate and the angular rate in time-sequenced
- share mode;
- using the stored calibration data to calibrate the acceleration rate and
- angular rate of the accelerating object based upon temperature and misalignment
- of the plurality of sensors on the object;
- computing a direction cosine matrix representation of attitude of the
- 21 accelerating object based upon the angular rate and a corrective angular rate of
- 22 the accelerating object;

23	multiplying the direction cosine matrix with a compensated acceleration
24	rate to obtain a true acceleration of the object without tilt;
25	generating a corrective rate signal based upon the true acceleration of the
26	object without tilt; and
27	extracting Euler angles from the direction cosine matrix for producing a
28	representative output.
1	16. The system of claim 15 further comprising:
2	a plurality of magnetic sensors coupled to the processor and configured to
3	provide a correction rate for yaw axis acceleration.
1	17. A method of determining an attitude of an accelerating object
2	exclusively from sensors of acceleration and angular rate, comprising:
3	performing an initial calibration of the plurality of sensors configured to
4	sense the acceleration rate and the angular rate of an accelerating object;
5	sensing the acceleration rate and the angular rate of the accelerating object
6	by use of the plurality of sensors;
7	converting the acceleration rate and the angular rate in time-sequenced
8	share mode;
9	using stored calibration data to calibrate the acceleration rate and angular
10	rate of the accelerating object based upon temperature and misalignment of the

- 11 plurality of sensors on the object;
- computing a direction cosine matrix representation of attitude of the
- accelerating object based upon the angular rate and a corrective angular rate of
- 14 the accelerating object;
- multiplying the direction cosine matrix with a compensated acceleration.
- rate to obtain a true acceleration of the object without tilt;
- generating a corrective rate signal based upon the true acceleration of the
- 18 object without tilt; and
- 19 extracting Euler angles from the direction cosine matrix for producing a
- 20 representative output.
- 1 18. A method for determining an attitude of an accelerating object
- 2 exclusively from acceleration and angular rate, comprising:
- determining an angular rate of the object for conversion to a direction cosine
- 4 matrix;
- 5 determining a level frame acceleration value of the object based upon the
- 6 direction cosine matrix and an acceleration of the object; and
- supplying attitude error and rate sensor bias estimates to a Kalman filter
- 8 operating on the level frame acceleration value as a reference to determine the
- 9 attitude of the object.

- 19. The method of claim 18 in which attitude error estimate includes 1 determining: 2 acceleration magnitude from acceleration information along multiple 3 orientation axes excluding gravity orientation; and 4 invalidating attitude determination in response to the acceleration magnitude 5 exceeding a selected value as indicative of a dynamic maneuver. 6 20. The method according to claim 18 in which attitude determination is 1 invalidated in response to yaw rate information exceeding a selected value as 2 indicative of a turn maneuver. 3 21. The method according to claim 18 including also supplying heading 1 2 information to the Kalman filter operating on the level frame acceleration value as 3 a reference to determine the attitude of the object. 22. The method according to claim 21 in which heading information 1 includes compass heading data. 2 23. The method according to claim 21 in which heading information 1 includes magnetometer data. 2
- 2 includes GPS information.

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The method according to claim 21 in which heading information

- 1 25. The method according to claim 20 in which yaw rate information
- 2 supplied to the Kalman filter prior to the indicated turn maneuver is supplied for
- 3 the duration of the yaw rate information exceeding the selected value.
- 1 26. The method according to claim 25 in which the state model noise
- 2 covariance of the Kalman filter is lowered during the acceleration magnitude
- 3 exceeding the selected value.
- 1 27. The method according to claim 25 in which the weighting of the
- 2 accelerometer attitude reference is lowered in the Kalman filter during the yaw rate
- 3 information exceeding the selected value.
- 1 28. The method according to claim 18 in which the determination of
- 2 angular rate of an object includes manipulating the object through a predefined set
- of maneuvers including an initial position as the final position of the maneuvers,
- 4 and estimating calibration parameters therefrom.
- 1 29. The method according to claim 28 in which a Kalman filter calculates
- 2 the calibration parameters from acceleration and angular rate data from the object
- 3 as manipulated through the set of maneuvers.